LACIE-00506
JSC-13737

LARGE AREA CROP INVENTORY EXPERIMENT (LACIE)

7.9-10063
TM 79928

"Made available under NASA sponsorship in the interest of early and wide dissemination of Earth Resources Survey Program information and without liability for any use made thereof."

NASA NOAA USDA

(E79-10063) LARGE AREA CROP INVENTORY EXPERIMENT (LACIE). DETECTING AND MONITORING AGRICULTURAL VEGETATIVE WATER STRESS OVER LARGE AREAS USING LANDSAT DIGITAL DATA (NASA) 26 p HC A03/MF A01 G3/43 N79-13470 Unclas 00063

DETECTING AND MONITORING AGRICULTURAL VEGETATIVE WATER STRESS OVER LARGE AREAS USING LANDSAT DIGITAL DATA

NASA
National Aeronautics and Space Administration

Lyndon B. Johnson Space Center
Houston Texas 77058

APRIL 1978

DETECTING AND MONITORING AGRICULTURAL

VEGETATIVE WATER STRESS OVER LARGE

AREAS USING LANDSAT DIGITAL DATA

APPROVED BY

James L. Dragg

J. L. Dragg, Chief
Applications System Verification Test Branch

Earth Observations Division

Space and Life Sciences Directorate

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LYNDON B. JOHNSON SPACE CENTER
HOUSTON, TEXAS

April 1978

DETECTING AND MONITORING AGRICULTURAL VEGETATIVE WATER STRESS OVER LARGE AREAS USING LANDSAT DIGITAL DATA

David R. Thompson and Oscar A. Wehmanen

ABSTRACT

A technique utilizing transformed Landsat digital data (for detection of agricultural vegetative water stress) was developed during the 1976 South Dakota, U.S.A., drought. The procedure was expanded to the U.S. Great Plains during 1977 to evaluate the technique for detecting and monitoring vegetative water stress over large areas. The technique, Green Index Number (GIN), uses Landsat digital data from 5x6 nautical mile sampling frames (segments) to indicate when the vegetation within the segment is undergoing stress. At known growth stages for wheat, segments were classified as drought or non-drought areas. The remote sensing based information was compared to a weekly ground-based index (Crop Moisture Index) provided by the United States Department of Commerce. This comparison demonstrated good agreement between the 18-day remote sensing technique and the ground-based weekly data. The moisture-stress detecting procedure developed over a small geographic area (South Dakota) was adapted to a larger geographic region (U.S. Great Plains). During the 1977 crop year, Landsat data indicated that portions of the USSR and Australia wheat regions were undergoing drought. Drought isoline maps produced by GIN agreed with conventional sources.

INTRODUCTION

Drought is a common occurence for many parts of the world and often adversely influences the affected nations' economy. Meteorological indexes which provide methods of computing the extent and severity of general drought have been developed. The Palmer drought index is the most satisfactory method for monitoring drought. During periods when a major drought is developing and spreading, the Palmer index combines precipitation and temperature data which provides a means for routinely assessing the areal distribution of the various degrees of drought severity (Palmer, 1968; Julian and Fritts, 1968).

Palmer (1965) used a two-layer soil moisture model for estimating soil moisture deficiency on a month-by-month basis. These monthly variations are adequate for the study of drought; however, they do not reveal the shorter periods of soil moisture fluctuations which are important during strategic phases of plant growth. The earlier drought study was modified by Palmer (1968) to calculate a weekly index of soil moisture requirements. This index uses the same two-layer models to compute a weekly hydrological balance. It is published in the United States as the Crop Moisture Index (CMI) by USDA and NOAA. Although the CMI provides an indication of current plant-water relationships, it requires climatological analysis of a long record in order to derive the constants which define the moisture characteristics of the climate in the area of interest.

In many regions of the world, the necessary information to run the CMI is not available, not reliable, or not current. The use of remote sensing for drought monitoring would provide the capability to assess moisture conditions anywhere in the world on a regular basis in real time.

In the Large Area Crop Inventory Experiment (LACIE) (MacDonald, 1976), a technique using Landsat digital data to detect moisture stress was developed during the 1976 South Dakota drought (Thompson and Wehmanen, 1977). This technique, Green Index Number (GIN), was evaluated in 1977 over the U.S. Great Plains and utilized in real time in the analysis of the 1977 USSR and Australia wheat crop.

OBJECTIVES

In 1976, using Landsat digital data over a small geographic area, a procedure was developed for detecting and monitoring agricultural vegetative water stress. The objectives of this study were to evaluate the applicability of this procedure over a large area and to use the technique in operational monitoring of the 1977 USSR and Australian wheat crops.

APPROACH

LACIE 5x6 nautical mile sampling frames (segments) were selected throughout the United States Great Plains (Figure 1). During the 1977 crop year, these same segments were evaluated in real time and compared with identical segment data collected in 1976. The Green Index Numbers (GIN) were computed to indicate whether the vegetation was moisture stressed or normal. The 2-year remote sensing classification was compared to the CMI to evaluate the applicability of the technique over large areas. Also during the 1977 crop year, selected segments in USSR and Australia were monitored for stress. When stress was indicated, all segments in the region were processed and drought isoline maps were produced for these regions during the critical heading and grain filling periods.

Using ideas presented by Kauth and Thomas (1976), a screening number, the Green Index Number (GIN) was developed during 1976 drought in South Dakota (Thompson and Wehmanen, 1977). The Green Index Number is a value designated to summarize the condition of vegetation within a sampling frame. It is based on the ability to detect and measure the area of growing vegetation using all four Landsat bands and to measure its area within the region. In approximate terms, the GIN is the percentage of land in an area with a "healthy" cover of vegetation. The GIN is computed on a LACIE sample segment, an area (5x6 nautical miles) with 22,932 Landsat image elements (pixels). The data is processed using an automated screening procedure which rejects pixels with values which are unreasonable for agricultural area. This procedure was established empirically after inspecting many LACIE segments. The procedure for computing GIN is defined by:

$$\text{For an observation where } X = \begin{array}{c} \text{Landsat Channels} \\ X_1 \\ X_2 \\ X_3 \\ X_4 \end{array}$$

$$Z \text{ is computed, where } Z = \begin{array}{c} Z_1 \\ Z_2 \\ Z_3 \\ Z_4 \end{array}$$

$$Z = RX$$

where,

$$R = \begin{array}{cccc} .433 & .632 & .586 & .264 \\ -.290 & -.562 & .600 & .491 \\ -.824 & .533 & -.050 & .185 \\ .223 & .012 & -.543 & .809 \end{array}$$

Each vector is inspected automatically, and any vector having values unreasonable for agricultural data is discarded using the following procedure:

A pixel is accepted as good only if:

$$Z_1 < 100$$

$$-8 < Z_2$$

$$-19 < Z_3$$

$$-5 < Z_4 < 15$$

Once the screening has been performed, the histogram of the value Z_2, truncated to integer, is accumulated for good pixels. Z_2 is defined as the greenness channel in the Kauth-Thomas transformation and is a weighted difference of the infrared and visible channels. Bare soil has a low greenness level which changes with haze level and sample segment location. The soil greenness, s_1, for each segment is estimated to the greenness of that pixel greener than only 228 (approximately 1%) of the other good pixels. The greenness scale is normalized so that the estimated soil greenness is zero, thus, the green number, g, for a pixel is $g = Z_2 - s$. The green number contains information about green vegetation. To compute GIN, the pixels with $g \geq 15$ are counted, divided by 22,932 and multiplied by 100. The level 15 was observed empirically to represent healthy green agricultural vegetation. The GIN is an estimate of the percentage of pixels in a Landsat scene having green numbers high enough (≥ 15) to indicate full cover of green vegetation. It is computed using only Landsat data.

It was determined during the 1976 South Dakota drought that a plot of GIN versus acquisition time for a normal, predominantly wheat segment should follow a predetermined curve (Figure 2). If an observed point for a segment fell into the shaded region, the segment was classified as drought affected. The bounds for the shaded region were defined empirically with t defined as the approximate spring emergence in days. For different areas of years, the shaded area is moved along the y axis from side to side to match the green-up curve. The bounds for the shaded region are such that a normal agricultural segment greens up at a rate greater than 1/2 percent per day for 40 days and it exceeds a GIN value of 20 for 30 days. After this time, the wheat in a region has completed grain filling and is harvested and the greenness of the region may decrease. Each acquisition for a segment was plotted and the segment was classified as moisture stressed or not moisture stressed. For comparison, these segments were also classified using the CMI for Crop Reporting Districts (CRD). A CRD was classified as drought affected if its CMI fell below -0.5 for 2 consecutive weeks. Both classifications were restricted to similar time frames. It was possible for a segment to start normal, and then undergo moisture stress. If the GIN classification did not agree with the CMI at all times, the GIN was considered as not agreeing with the CMI (Table 1).

RESULTS

U.S. Great Plains Results

The data used in this study consisted of 36 LACIE segments located throughout the U.S. Great Plains wheat growing region (Figure 1). These segments contained at least 5 percent agricultural cropland. The final data set consisted of 70 segment years[1] for the 36 LACIE segments (Figure 1, Table 1). The remote sensing classification was evaluated against the Crop Moisture Index (CMI). This index measures the degree to which moisture requirements of growing crops were met during the previous week. The index is computed from average weekly values of temperature and precipitation. These values are used to calculate, using previous soil moisture condition and current rainfall, the actual moisture loss. If the potential moisture demand, or potential evapotranspiration, exceeds available moisture supplies, actual evapotranspiration is reduced and the CMI gives a negative value. However, if moisture meets or exceeds demand the index is positive. The CMI represents the average conditions over a several-county region (Crop Reporting District), so local moisture conditions may vary because of differences in rainfall distribution or soil types. The specific type of agriculture is not considered in the CMI, but it assumes a water-use curve typical of the leaf area index of the crops which predominate in the region.

---

[1] A segment year is defined as an observation of one segment for a growing season.

The final data set of 70 segment years shows good agreement between the remote sensing classifications (GIN) and the CMI classification (Table 1). The contingency table (Table 2), which compares the two classification methods, shows that the classification based on the CMI and GIN are the same 85% of the time. A chi-square test was employed to test the hypothesis that GIN and CMI are independent. The resulting test statistic, which under the above hypothesis follows a chi-square distribution with one degree of freedom, was highly significant indicating that GIN and CMI are not independent. It was concluded that the GIN is detecting moisture through crop responses, and this procedure, developed over a small region, is extendable to larger areas.

An inspection of the eleven disagreements on the classification results (Table 1) disclosed that the soil types at the segment location have a different water holding capacity than that used in the CMI model (5 disagreements). Also, rainfall patterns at the segment location differ from the amount recorded at the weather stations used in computing the CMI. This is reflected in that the other 6 disagreements occurred in segments that were located on the edge of the CRD, and thus the CMI does not necessarily represent the conditions that exist at the segment location.

USSR AND AUSTRALIA RESULTS

During the 1977 crop year, the Green Index Number (GIN) monitoring program was run on selected LACIE 5x6 nautical mile sample segments located in the wheat regions of USSR and Australia. When moisture stress was indicated on these segments by the GIN program, all LACIE segments in these areas were monitored and drought isoline maps were produced for Landsat passes during the critical grain filling stage. For the USSR, two passes during July represented this period, and for Australia, two passes during late September and early October.

The GIN monitoring program showed that parts of the USSR spring wheat region was undergoing moisture stress during the Landsat passes of July 2-18, 1977 (Figure 3). During this time, the GIN value should be 20 or greater for adequate moisture. The next Landsat overpass (July 19-July 30, 1977) showed that the area was still undergoing moisture stress (Figure 4). A composite of the two GIN classification results show that much of the USSR spring wheat region experienced moisture stress during the most critical growth stage (Figure 5). While ground truth is not readily available for this area, the U.S. agricultural attache (personal communication) verified that this region had undergone moisture stress at that time. The official USSR small grains production estimates released were down considerably from normal (192 million metric tons vs. 225 million metric tons) and thus also tend to verify that adverse conditions had occurred.

The critical growth stage for wheat in Australia is during late September and October when the crop is heading and the grain is beginning to fill. All LACIE segments acquired for two Landsat overpasses during this time were run through the GIN monitoring program. The Landsat pass for September 14-25 shows that much of the area was undergoing moisture stress (Figure 6). The next overpass (October 2-13) verified the area (Figure 7). A composite map shows that much of the wheat producing area of Australia was undergoing moisture stress (Figure 8). A drought review of Australia is produced by the Australian government each month. The October 1977 report shows the conditions that existed during the corresponding GIN interpretation of drought conditions (Bureau of Science, 1977). These conditions are shown in Figure 9. The GIN classification represents only the area where LACIE segments are located. A comparison of Figures 8 and 9 shows general agreement. The Australia drought conditions are based on precipitation data and a comparison with long-term averages. It does not take into account soil moisture available. An inspection of Landsat 100x100 nautical mile color IR images indicates that the vegetation is only marginally affected by the serious drought in the southeastern part of the country as reflected by the Australia drought report.

CONCLUSIONS

The resul s of this study demonstrate that a technique developed for monitoring agricultural vegetative water stress over a small geographic region is expandable to large geographic areas and to different parts of the world. Thus, in areas of the world where ground truth is not available or reliable, it is possible to detect and determine the areal extent of moisture stress using Landsat in an automatic mode.

REFERENCES

Bureau of Science, Oct. 1977: Drought Review, Australia, Number 98, Milbourne, Vic., 13 pp.

Julian, P. R.; and Fritts, H. C., 1968: On the Possibility of Quantitatively Extending Climatic Records by Means of Dendroclimatological Analysis. American Meteorological Society, Proc. of First Statistical Meteorological Conf. (Hartford Conn.), May 27-29, 180 pp.

Kauth, R. J.; and Thomas, G. S., July 1976: The Tasselled Cap -- A Graphic Description of the Spectral-Temporal Development of Agricultural Crops as Seen by Landsat. Proc. Symp. on Machine Processing of Remotely Sensed Data, Purdue Univ. (W. Lafayette, Ind.) IEEE cat. 76, CH1103-1-MPRSD.

MacDonald, R. B., Oct. 1976: The Large Area Crop Inventory Experiment, 2nd Annual William T. Pecora Memorial Symp. (Sioux Falls, S. Dakota).

Palmer, W. C., 1968: Keeping Track of Crop Moisture Conditions Nationwide, The New Crop Moisture Index. Weatherwise, 21, pp. 156-161.

Palmer, W. C., 1965: Meteorological Drought, U.S. Weather Bureau Paper 45, 45 pp.

Thompson, D. R.; and Wehmanen, O. A., April 1977: The Use of Landsat Digital Data to Detect and Monitor Vegetation Water Deficiencies, Eleventh Int. Symposium on Remote Sensing of Environment (Ann Arbor, Michigan), pp. 925-931.

TABLE 1. RESULTS OF GIN AND CMI CLASSIFICATIONS

D = Moisture stressed conditions; W = Normal conditions; - = No data

Segment	1977 GIN	1977 CMI	1976 GIN	1976 CMI
1560	W	W	D	W
1605	W	W	W	W
1388	W	W	-	-
1521	W	W	W	D
1595	W	W	W	W
1596	W	W	W	W
1056	W	W	D	D
1084	W	W	D	D
1015	D	W	D	D
1020	W	W	D	D
1642	W	W	W	D
1644	W	W	W	D
1503	W	D	D	D
1592	W	W	W	W
1557	D	D	D	W
1260	W	W	D	D
1694	W	W	D	D
1670	W	W	D	D
1227	W	W	W	W
1231	D	W	D	W
1233	W	W	W	W
1238	W	W	W	W
1166	W	W	W	W
1264	W	W	D	D
1047	-	-	D	D
1048	W	W	D	D
1008	W	W	D	D
1010	W	W	D	D
1857	W	W	W	W
1861	W	W	D	W
1645	W	W	W	D
1884	W	W	W	W
1887	W	W	W	W
1892	W	W	W	W
1601	D	D	W	W
1538	D	D	W	W

TABLE 2. CONTINGENCY TABLE OF GIN AND CMI CLASSIFICATION METHODS

		CMI		
		Normal	Stressed	Total
GIN	Normal	43	5	48
	Stressed	6	16	22
	Total	49	21	70

$X^2_{(1)} = 27.89$*

*Significant at the .001 level

Figure 1. Map of U.S. Great Plains showing locations of LACIE 5x6 nautical mile sample segments.

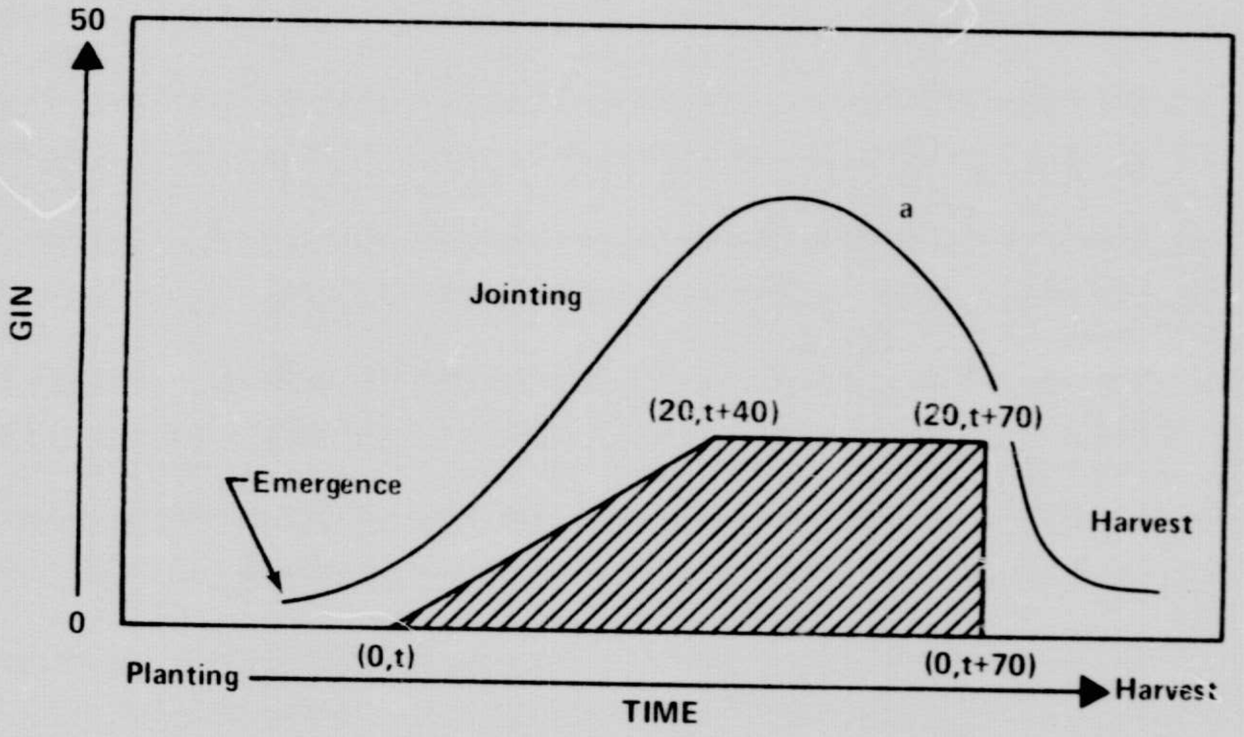


Figure 2. Green Index Number (GIN) time for a normal, predominantly wheat segment.

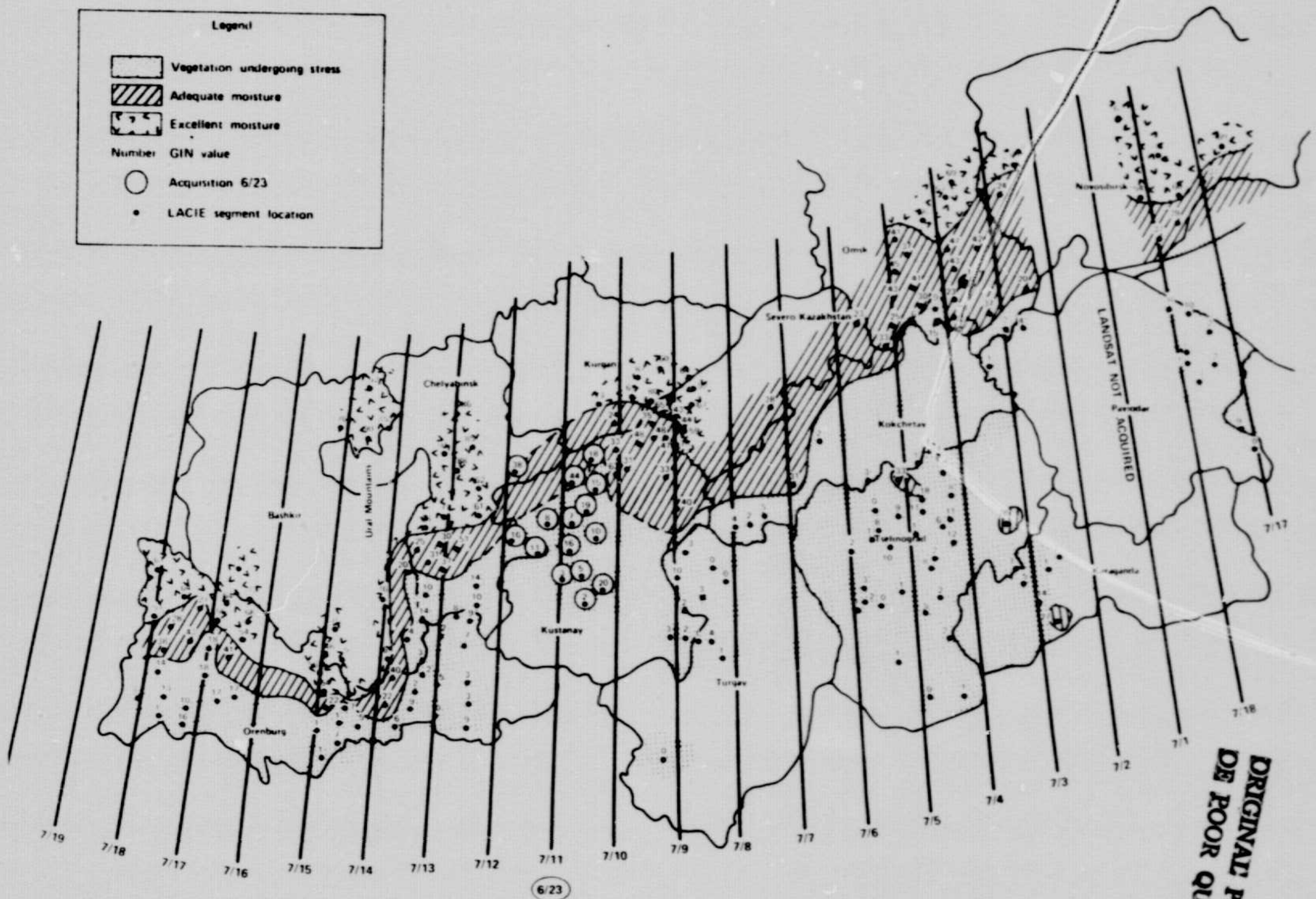


Figure 3. Moisture conditions over USSR spring wheat from the Green Index Number (GIN) monitoring program (Landsat data acquired June 23, 1977, and July 2 through July 19, 1977.)

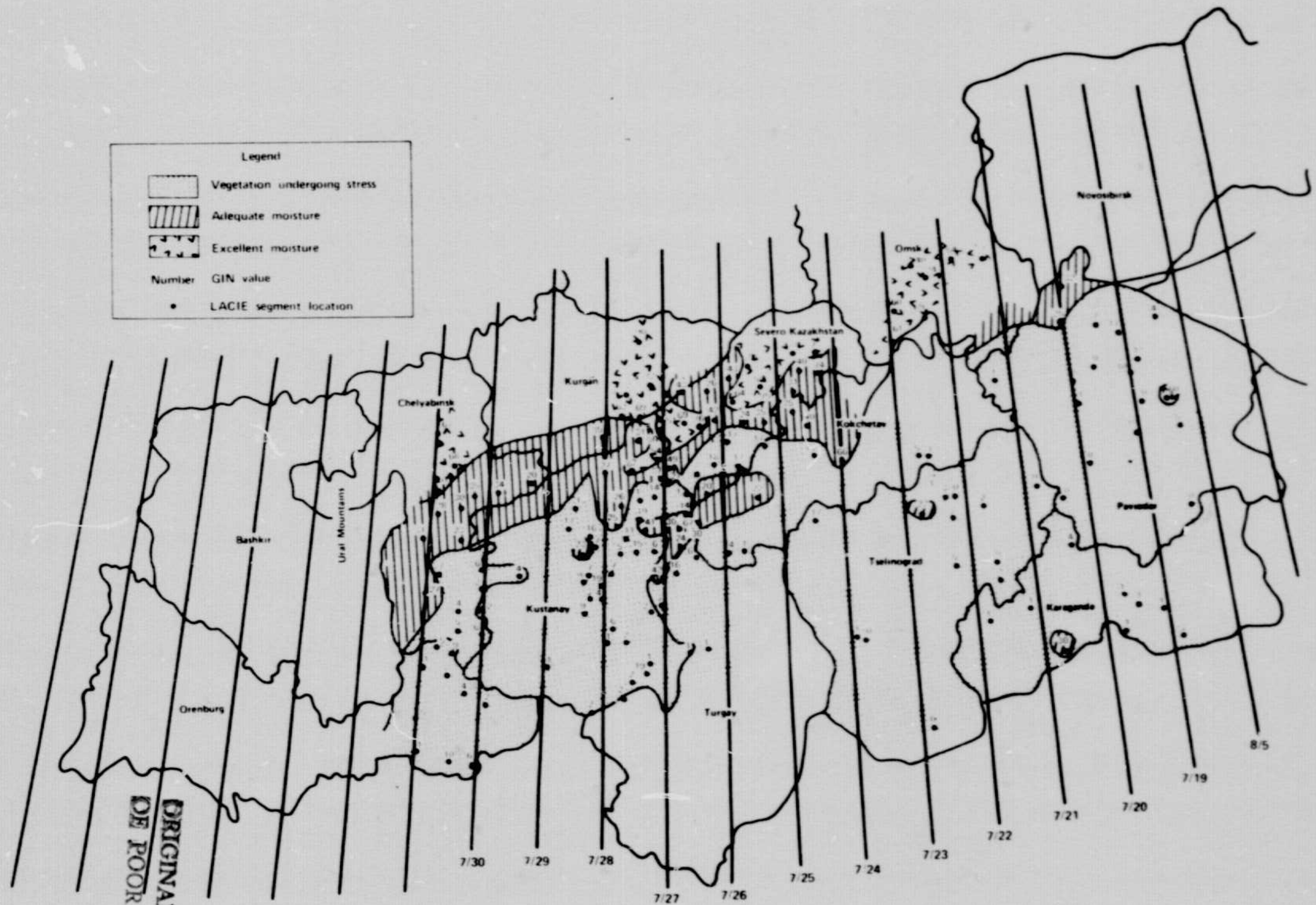


Figure 4. Moisture conditions over USSR spring wheat from the Green Index Number (GIN) monitoring program (Landsat data acquired July 19 through July 30, 1977.)

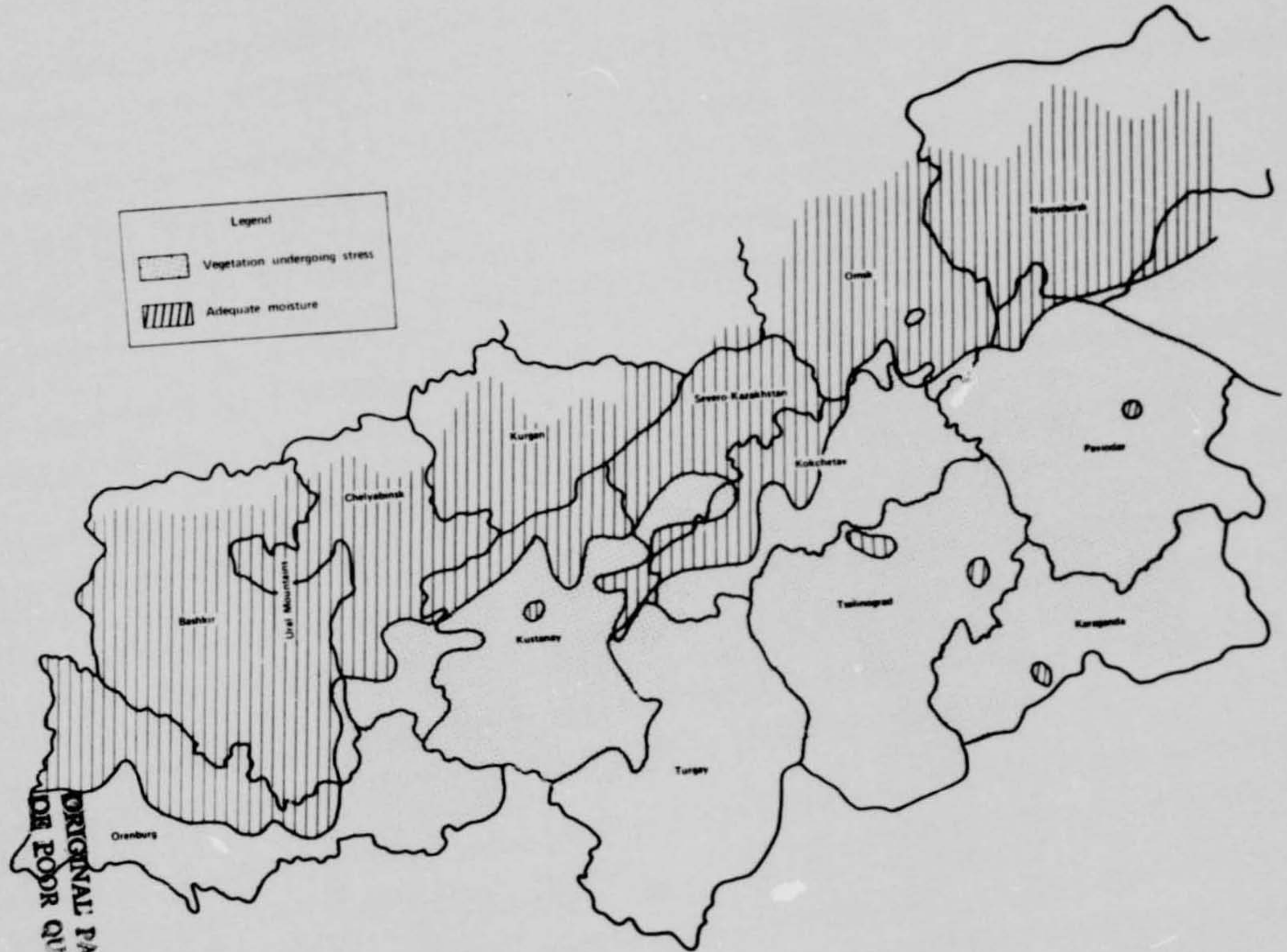


Figure 5. Moisture conditions over USSR spring wheat from the Green

Index Number (GIN)

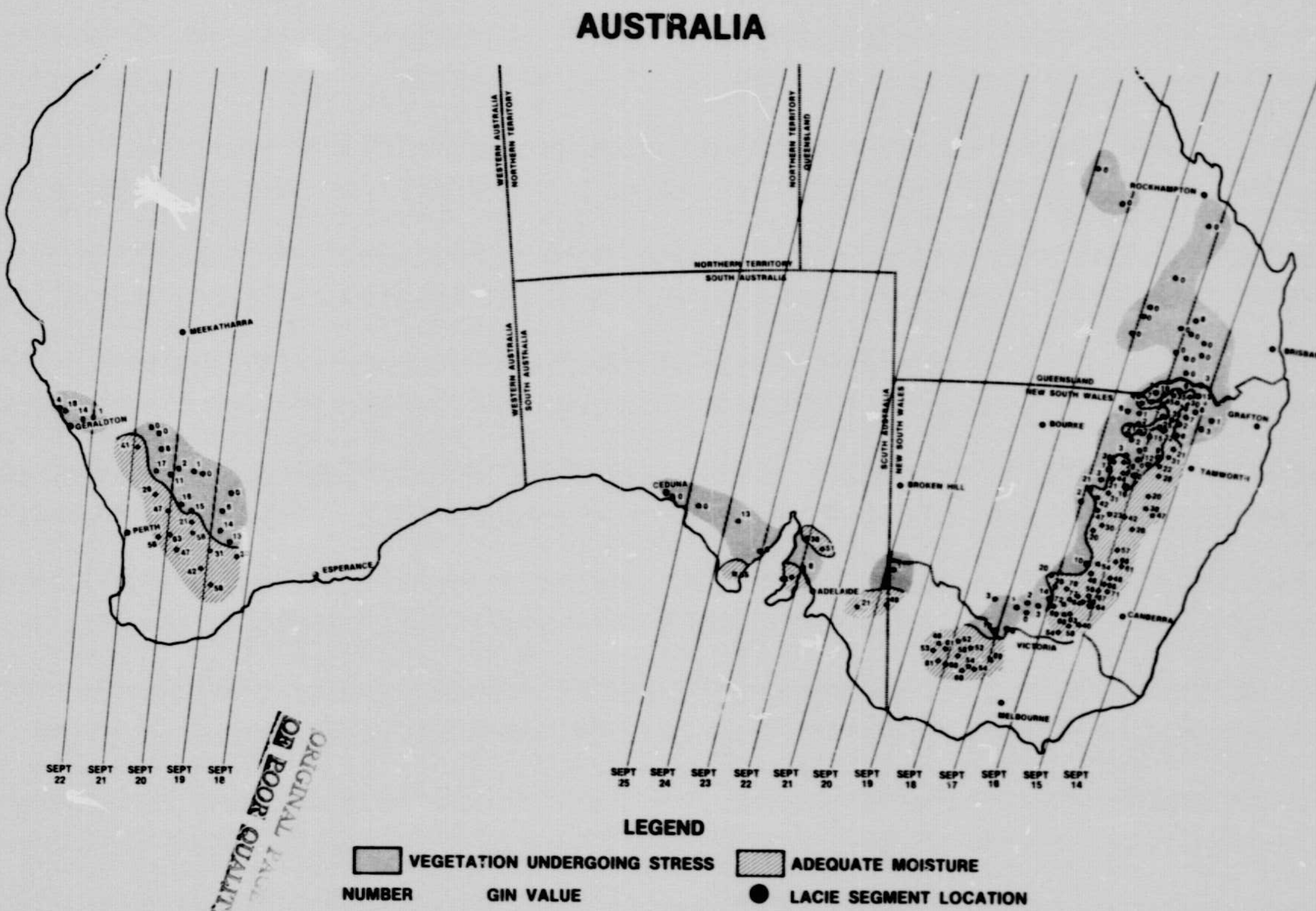


Figure 6. Moisture conditions over Australia wheat from the Green Index Number (GIN) monitoring program for September 14-25, 1977.

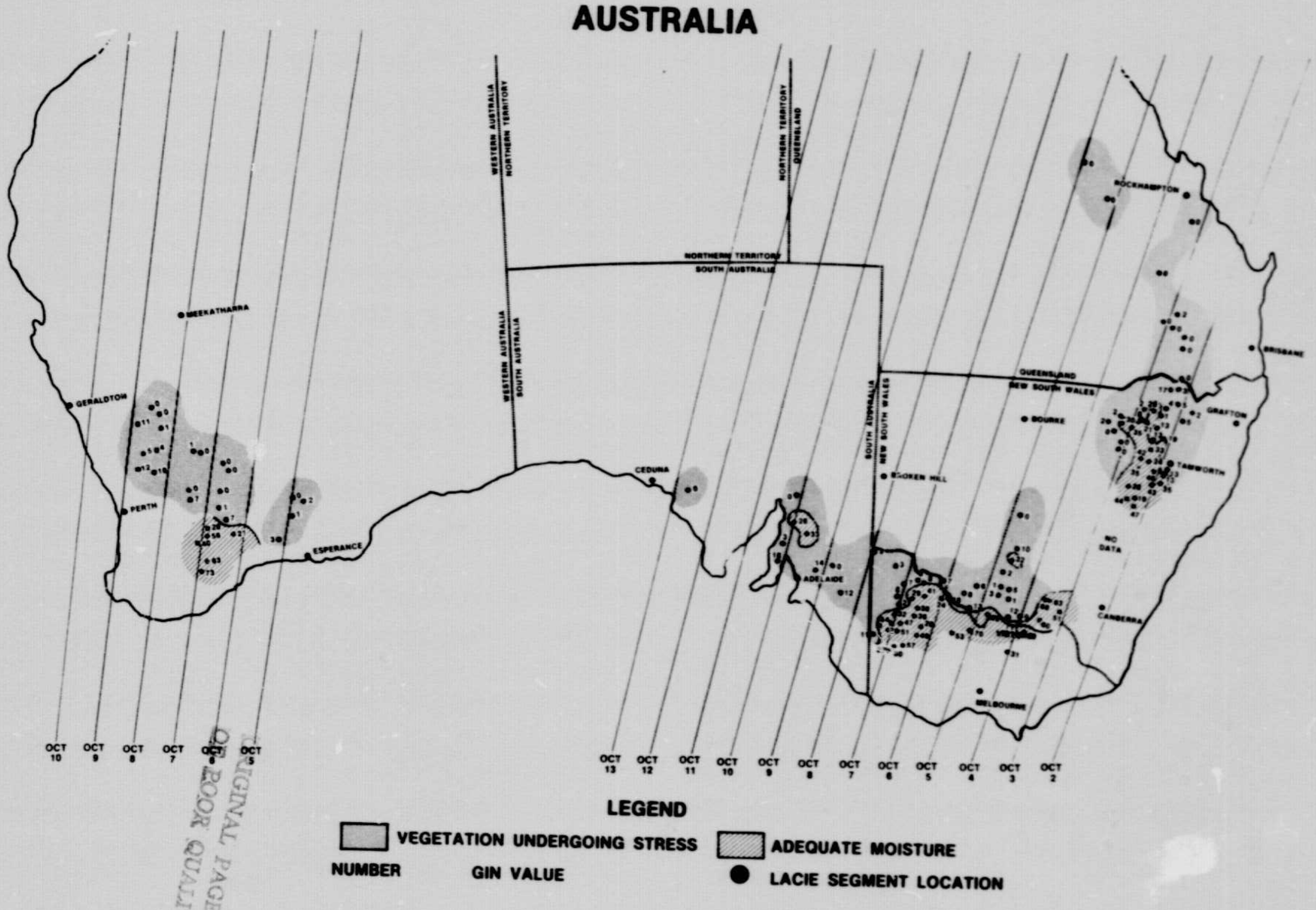


Figure 7. Moisture conditions over Australia wheat from the Green Index Number (GIN) monitoring program for October 2-13, 1977.

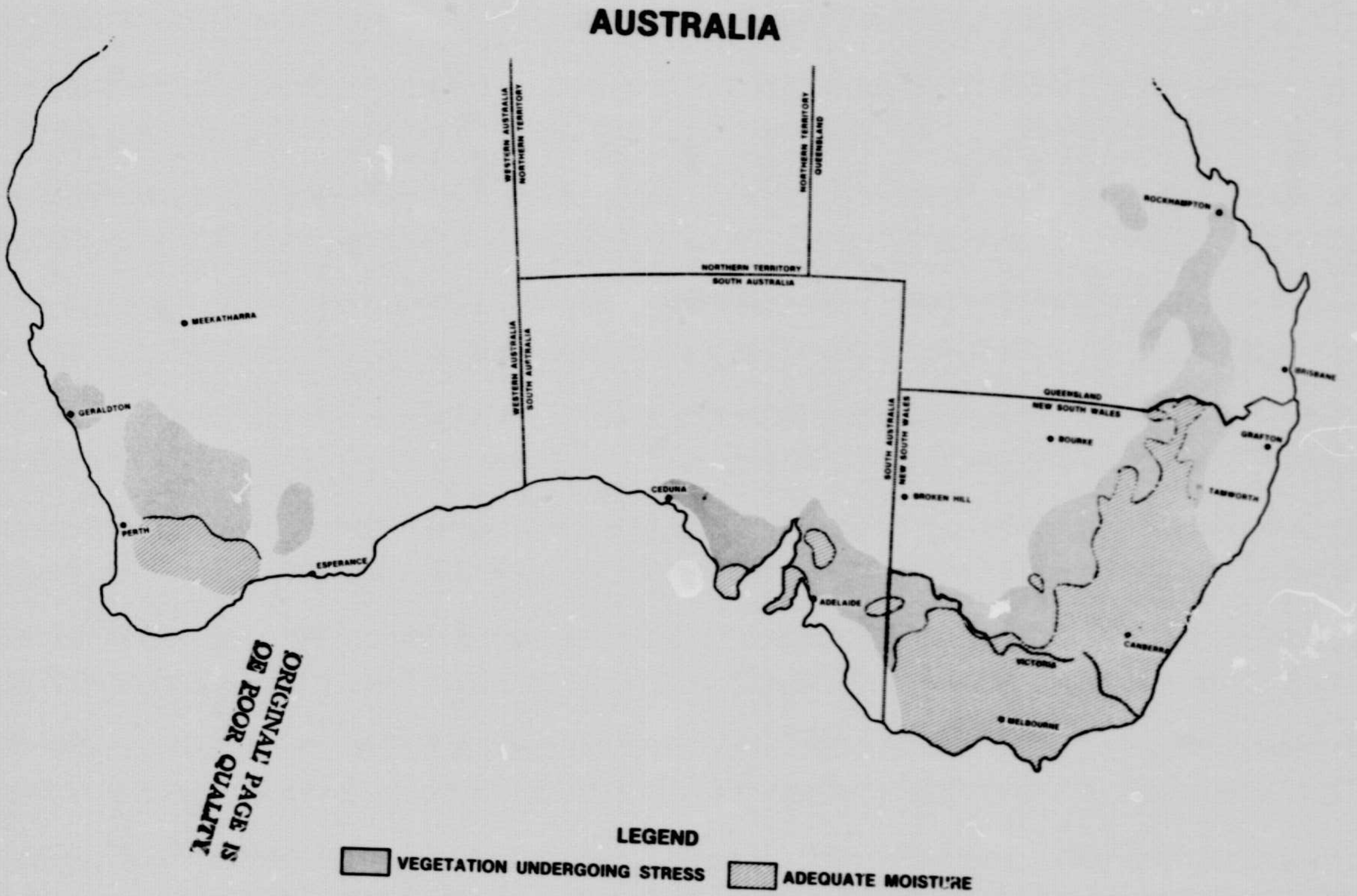
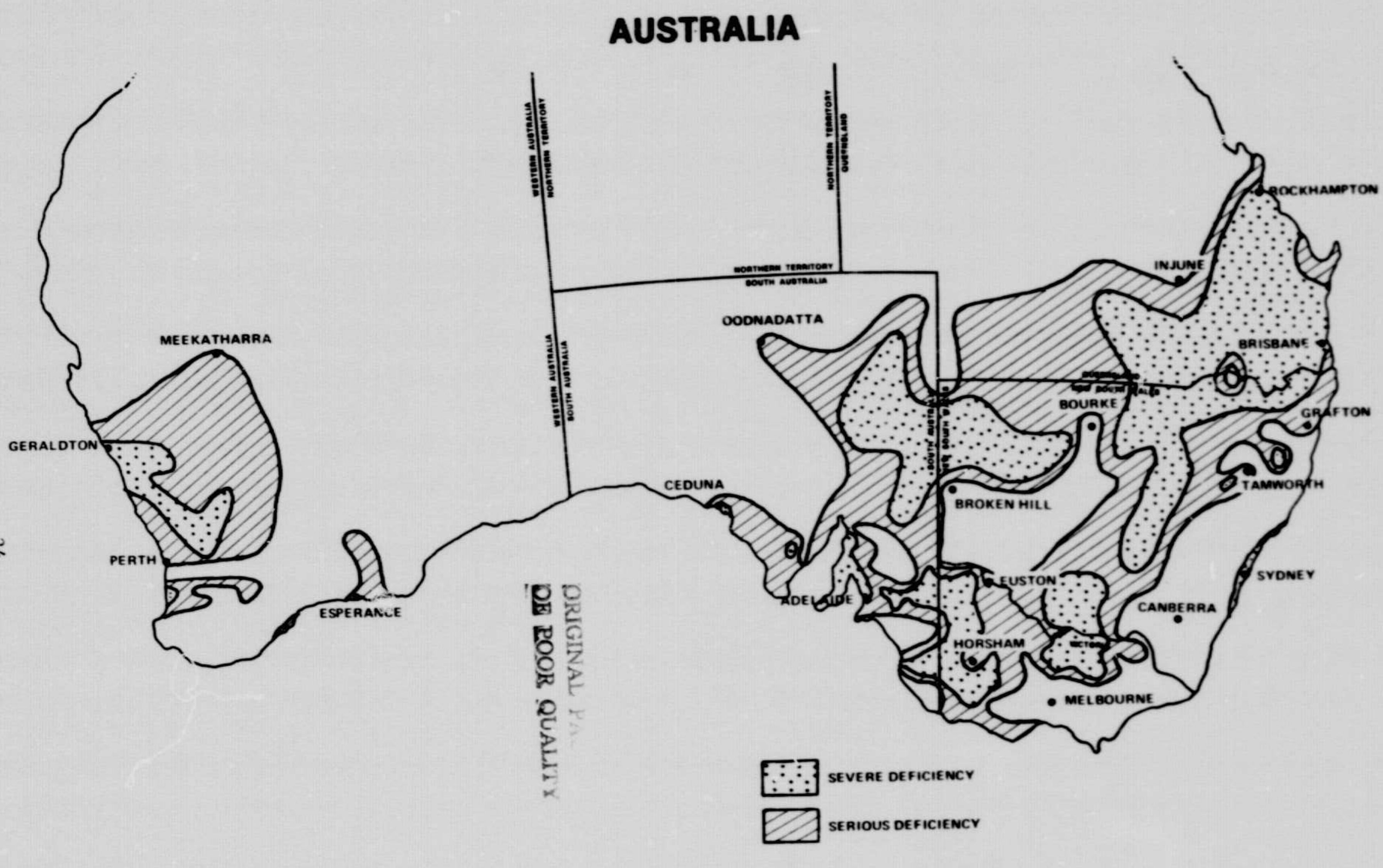


Figure 8. Moisture conditions over Australia wheat from the Green Index Number (GIN) monitoring program for September-October 1977.



ORIGINAL PAGE IS
OF POOR QUALITY

Figure 9. Area of moisture deficiency in Australia as of October 1977 as indicated by rainfall deficiencies.